The technical report on the Empirical Peak Flow Reduction Model (EPRRM) used to develop the receiving water limitations for peak flow reductions follows.



# Empirical Peak Flow Reduction Model for the

# Watershed-wide Waste Discharge Requirements for Elk River and Freshwater Creek, Humboldt County, California

June 21, 2005

***Provisional Draft***

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## *Introduction*

This technical report presents the empirical peak flow reduction model and methodology utilized by the Regional Water Quality Control Board (Regional Water Board) staff for the Watershed-wide Waste Discharge Requirements (WWDRs) for Elk River and Freshwater Creek, Humboldt County, California, in order to reduce peak flows and the consequent nuisance flooding. While flooding is a natural occurrence in any watershed, discharges of sediment and the removal of tree canopy have combined to reduce channel capacity and increase peak flows in a manner that substantially increases the frequency, magnitude, and duration of flooding in Elk River and Freshwater Creek. Flooding in these watersheds creates significant health and safety problems, preventing people from getting to and from their homes, schools and jobs, as well as inundating houses, bridges and roads, and septic systems.

Abatement of the nuisance flooding by physically removing built-up sediment and streamside vegetation, thereby increasing channel capacity and allowing peak flows to move through these systems without overtopping channel banks has long been discussed as a potential solution. In response to Regional Water Board direction in December 2003, Regional Water Board staff (hereinafter staff) met with various permitting and potential funding entities to evaluate options for instream sediment removal in these watersheds. Staff concluded that a feasibility study would be required prior to taking any action. Staff further determined that no funding, public or private, was available for study preparation or implementation, nor was any entity prepared to accept lead responsibility. PALCO expressed an interest in pursuing sediment removal options in April 2002 as part of Regional Water Board sponsored mediation attempts. However, no specific proposals have been submitted to the Regional Water Board. PALCO indicated a renewed interest in pursuing this option in March of 2005. Although PALCO is providing some funding for a feasibility study, no plan exists to increase channel capacity in the foreseeable future.

Therefore, the application of the empirical peak flow reduction model as proposed by staff in the WWDRs is to control cumulative increases in peak flows by limiting canopy removal and thereby reducing the volume of storm water runoff from future harvest areas. The model is employed to reduce the predicted magnitude, frequency, and duration of nuisance flooding events over time, as a function of canopy removal. This approach builds upon previous efforts to limit peak flow increases by incorporating new data, protecting beneficial uses of water and lessening the nuisance flooding conditions.

## *Work Conducted by California Licensed Professionals*

The work described in this report constitutes the practices of geology and civil engineering, according to the California Professional Engineers Act (California Business and Professions Code §§ 6700-6799, 2005), the Geologist and Geophysicist Act (California Business and Professions Code §§ 7800-7887, 2005), and associated rules and regulations. The work has been performed by a team of California licensed professional engineers and geologists on staff at the Regional Water Board. These individuals include, but are not limited to, Matthew Buffleben, P.E. # C65694; Adona White, P.E. # C68111; and Mark Neely, C.E.G. # 1572

This report is considered provisional because the results presented in it may change through the discovery of new data or through the refining of initial necessary assumptions during the public review process required for the WDRs under the California Environmental Quality Act (CEQA). Once the public review process is complete, staff will issue a revised set of WDRs and will finalize this report, certifying under appropriate stamps, seals, and signatures that it was prepared in accordance with, and meets professional standards contained in applicable laws and regulations under the California Business and Professions Code. The certified report will then be submitted as supporting documentation for the revised set of WDRs to be considered by the Regional Water Board at a properly noticed public hearing.

## *Background*

### Effects of flooding

Frequent flooding limits the residents' ingress and egress to their property. In particular, the US Army Corps of Engineers (1975), in their report on flooding in Freshwater Creek, described several potential hazards: people can become trapped in their homes or vehicles; the force of the floodwaters and debris deposits can rupture waterlines and risk contamination of domestic water supplies; and isolation of areas by floodwater creates hazards in terms of medical, fire, or law enforcement emergencies.

Property damage includes fences being knocked down during floods, loss of agricultural productivity through deposition of silt on crops, threats to septic systems, loss of water supplies by filling of pools with sediment, and wear and failure of pumps and other mechanical devices. When floodwaters enter homes, they cause damage to floorings, furniture, walls, etc. and require residents to raise furniture and property for its protection. Cleanup after a flood event is costly and time-consuming. Residents attempt to protect their homes from floodwaters by using sandbags or by constructing walls and levees. Due to increased risk of flooding, property values are reduced and flood insurance is difficult to obtain and expensive to maintain.

Nuisance expresses itself in different forms: emotional and psychological distress of floodwaters entering a property or home, financial hardship, and anxiety. All of these effects constitute a nuisance condition.

### Freshwater Creek and Elk River

Residents downstream of PALCO's timber harvesting activities in Elk River and Freshwater Creek filed formal complaints with the Regional Water Board (and other State agencies) contending the increased magnitude (i.e. water surface elevation) and frequency of flooding in the lower portion of the two watersheds have and are continuing to significantly affect the beneficial uses of water and the public health and safety of downstream residents. They also reported significant changes in stream morphology, such as the filling of in-stream pools with sediment corresponding with sediment discharges from upstream timber harvesting activities. Subsequent staff evaluations, monitoring efforts, and reports have corroborated these resident reports.

The increased frequency and magnitude of flooding in Elk River and Freshwater Creek results primarily from a combination of two factors: reduced channel capacity and altered hydrology. A decrease in channel capacity has been documented in Elk River (Patenaude 2004) and in Freshwater Creek (Caltrans 2003). Studies from Caspar Creek experimental watershed confirm that peak flow response to logging results from the reduction in vegetative cover. Reducing vegetative cover, particularly large trees, reduces evapotranspiration and rainfall interception (Ziemer 1998). Hydrology is also altered by changes that lower infiltration (for example, from compaction of soil) and increase the stream network (for example, construction of inside road ditches and gullies) in the watershed.

Waste Discharge Requirements

Waste Discharge Requirements must implement the Basin Plan, which prohibits the discharge of sediment waste from timber harvest-related activities in amounts deleterious to beneficial uses (*Water Quality Control Plan for the North Coast Region* (Basin Plan): pp. 4-28 – 4-30), and must be crafted to address the need to prevent nuisance (Water Code section 13263(a)).

California Water Code section 13050 defines nuisance to mean anything, which meets all of the following requirements:

(1) Is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property.
(2) Affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal.
(3) Occurs during, or as a result of, the treatment or disposal of waste.

Since the criteria of Water Code section 13050 are met, it is the right and responsibility of the Regional Water Board to control the nuisance flooding in Freshwater Creek and Elk River. Based on the extensive documentation of nuisance flooding, the relationship of increased peak flows to canopy removal, and the obligation of the Regional Water Board to address nuisance and to protect beneficial uses, staff is recommending a application of the peak flow reduction model in a manner that will reduce flooding when applied to the Elk River and Freshwater Creek watersheds through the WWDRs.

### *Empirical Peak Flow Reduction Model*

To reduce nuisance conditions, staff determined that the use of the empirical peak flow reduction model (peak flow model) was the most appropriate for use in the Elk River and Freshwater Creek watersheds. Staff selected a peak flow model that relates the effects of vegetation removal to increases in peak flow, based on studies in the Caspar Creek watershed in Mendocino County. Staff then identified the values for key parameters in the peak flow model that includes a margin of safety and accounts for seasonality (wet versus dry soil conditions). Finally, staff modeled future conditions to determine appropriate reduction of the current nuisance conditions.

For the purposes of the WWDRs, and where possible, it is those flood waters that inundate key points on roads limiting numerous residents from free movement that are targeted. This threshold is defined by staff as the threshold for nuisance.

Peak flow model background

In selecting an appropriate model to address peak flow conditions associated with vegetation removal, staff used the peak flow model developed from results of the Caspar Creek Experimental Watershed by the scientists at the USDA Forest Service Redwood Sciences Laboratory (peak flow model).

There are several reasons why staff, as well as PALCO and CDF, use the Caspar Creek peak flow model. Caspar Creek (Mendocino County) is one of the most intensively studied watersheds in the northern California coast and Pacific Northwest, and has substantially advanced the scientific understanding of forest hydrology and sediment delivery. The Caspar Creek study is uniquely appropriate because it evaluated the hydrologic effects of conducting timber harvest and related activities in second-growth redwood forests. Also, Caspar Creek is representative of conditions in many northern California coast watersheds. The Caspar Creek watershed is similar to the Elk River and Freshwater Creek watersheds in terms of its coastal location, vegetation, rainfall patterns, and land use.

This peak flow model has been previously used for evaluating and regulating runoff from timber harvest activities in both Freshwater Creek and Elk River. Pacific Lumber Company (PALCO 2000) adapted equations from the published results of the Caspar Creek experiment (Lewis et al. 2001) and utilized them for conducting the watershed analysis required under their Habitat Conservation Plan (HCP). Lisle et al. (2000a) reviewed the flooding analysis for the watersheds to determine, in part, the hydrologic changes resulting from past and future timber harvesting. In response to a request by California Department of Forestry and Fire Protection (CDF), the authors issued *Addendum: Review of Freshwater Flooding Analysis Summary* (Lisle et al. 2000b) and provided a systematic explanation of how to apply the equations presented in PALCO 2000. CDF subsequently conducted analyses in both Freshwater Creek (Munn 2001) and Elk River (Munn 2002) to determine a canopy removal rate that would not result in an increase in peak flow over the current (2001/2002) conditions. In 2001 and 2002 respectively, CDF imposed allowable clearcut equivalent acreage limitations in the Freshwater Creek and Elk River watersheds. The CDF imposed limitations included 500 clearcut equivalent acres in Freshwater Creek and 600 clearcut equivalent acres in Elk River annually.

The peak flow model is helpful in guiding decisions regarding timber-harvest related runoff, because of its ability to track effects of timber operations from year to year, and its ease of use and objectivity. Although process-based models are preferred for many modeling exercises, using an empirical model in these watersheds is appropriate at this time. Process-based models require extensive input data due to the complexity of modeling hydrology and hydraulics. While watershed information is more abundant in the Elk River and Freshwater Creek watersheds than most other north coast watersheds, there is not sufficient data to allow for process-based modeling of the effects of timber harvesting on peak flows. As new data are developed, it may become more appropriate to consider process-based models in these watersheds. Until that time, staff believes that using an empirical model that does not require extensive data inputs is appropriate.

Description of the Caspar Creek Study and Results

In 1985, monitoring began for a new phase of timber harvest that was about to occur in North Fork Caspar Creek. Controlled experiments in Caspar Creek were designed and conducted to measure changes in hydrology and sediment transport resulting from timber harvesting activities. Monitoring data were collected over four years of pretreatment[1]. Timber harvests were conducted primarily over a three-year period and were monitored for at least four more years. Treatment was comprised of clearcut harvesting of 30% to 98% of treated watersheds, of which 81% were cable yarded and 19% tractor yarded. Additionally, 34% of the harvested timber was selectively logged from stream buffer zones, ranging from 15 - 46 m in width, depending on stream class. Treatments included construction of new roads, landings, and skid trails, as well as broadcast burning of four harvest units. Three tributaries were left as control watersheds. In all, fifteen gaging stations were monitored, including one on South Fork, five on North Fork, and nine on tributaries of North Fork (Lewis et al. 2001).

The peak flow model is based on the results from the observations of increases in peak flows following timber harvest activities. The analysis included 59 storms on 10 treated watersheds. Storm events were included when they had a recurrence interval of more than 7 times per year although a few smaller peaks were included in dry years (Lewis et al. 2001). Although monitoring was discontinued in several of the watersheds in 1996, Lewis and Keppeler (in press) report the results where monitoring was continued through hydrologic year 2003.

Runoff volumes vary with seasonal conditions, even for the same precipitation event. Lewis et al. (2001) used a wetness index to reflect seasonal differences. The wetness index is based on mean daily average stream flows in the South Fork Caspar Creek (a control watershed, unlogged since 1973). The decision to use streamflow rather than precipitation to calculate antecedent wetness conditions was based on the assumption that the history of the streamflow response would be a better predictor of streamflow than would the history of rainfall (Lewis et al. 2001). Furthermore, the wetness index was developed to reflect the soil moisture changes between the harvested and control areas that develop due to harvesting. The wetness of the watershed is calculated per Equation 1 where the daily discharges were accumulated and decayed using a 30-day half-life.

$$w_i = Aw_{i-1} + q_i \qquad \textbf{Equation 1}$$

Where,

$w_i$ = Wetness on day *i*

$q_i$ = The daily mean flow at South Fork Caspar Creek on day *i* (cfs)

$A$ = 0.97716, where $A^{30}$=0.5. It represents the 30-day half-life.

The antecedent wetness is the watershed's wetness of the day prior to the onset of the storm.

[1] Two units in the North Fork Caspar Creek watershed were harvested during pretreatment. However, the peak flow model accounts for this harvesting.

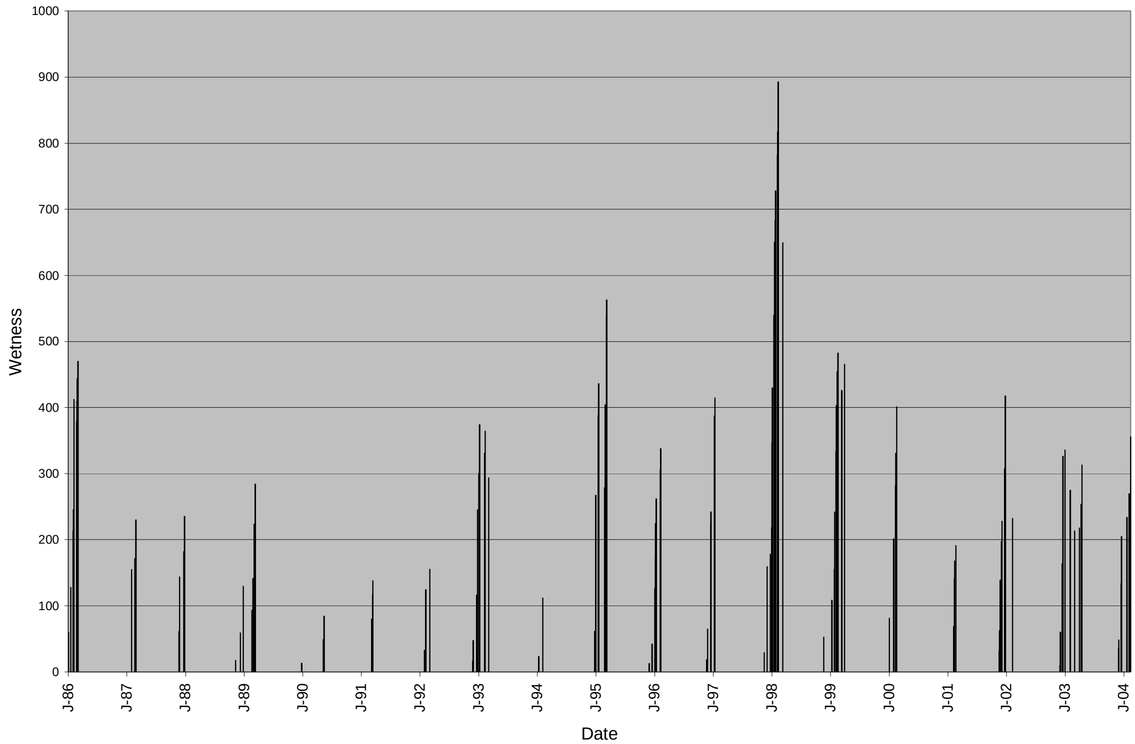


**Figure 1. Antecedent wetness for storms used in the Caspar Creek peak flow model.**

Staff analyzed the antecedent wetness data from hydrologic years (HY) 1986 through 2004. For the 19 years of data (see Appendix) the antecedent wetness ranged from 10 (dry conditions) to 892 (wet conditions). The antecedent wetness for storms that were used in the model are displayed in Figure 1. Note a large variability in the number of storms per year (2 to 14) as well as variability in wetness for each storm.

The distribution of antecedent wetness for the same time period is displayed as a boxplot in Figure 2. The bottom and top of the box present first ($25^{th}$ percentile) and third ($75^{th}$ percentile) quartiles, and contain within the box, the middle 50% of the values. The median ($50^{th}$ percentile) is marked by a line within the box and the mean is shown as an X. The whiskers extend to the values that fall within 1.5 * IQR (interquartile range). Outliers are plotted with asterisks (*) when they fall outside of this range.

The four outliers in Figure 2 represent four storms that occurred during the 1998 HY (Figure 1). It is interesting to note that 1998 had seven storms above the next largest wetness (563) that occurred outside of 1998 HY.

The median value is 224 while the mean value is 251. The first quartile is 116 while the upper quartile is 356. The distribution of the antecedent wetness is skewed to right (or “up” in the boxplot view).

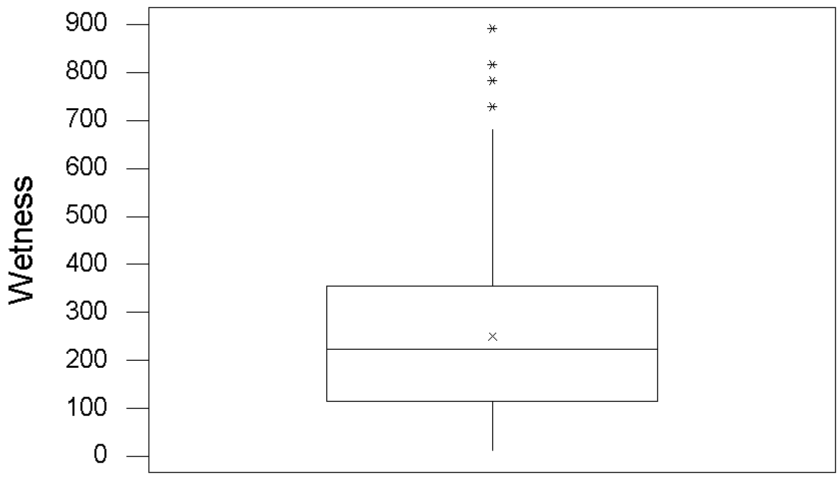


**Figure 2. Boxplot of the antecedent wetness distribution.**

Additional boxplots of the antecedent wetness are displayed in Figure 3 by hydrologic year and by the storm number for each year. The year to year variability in the wetness is apparent. It is interesting to note that for 17 of the 19 years of data, the mean is equal to or lower than the median. This result is expected because the low wetness values that occur in the beginning of the year lower the mean while the median is resistant to extreme values at the tails of the distribution. Increases in wetness by storm number also are apparent in Figure 3, with the wetness increasing throughout the winter period.

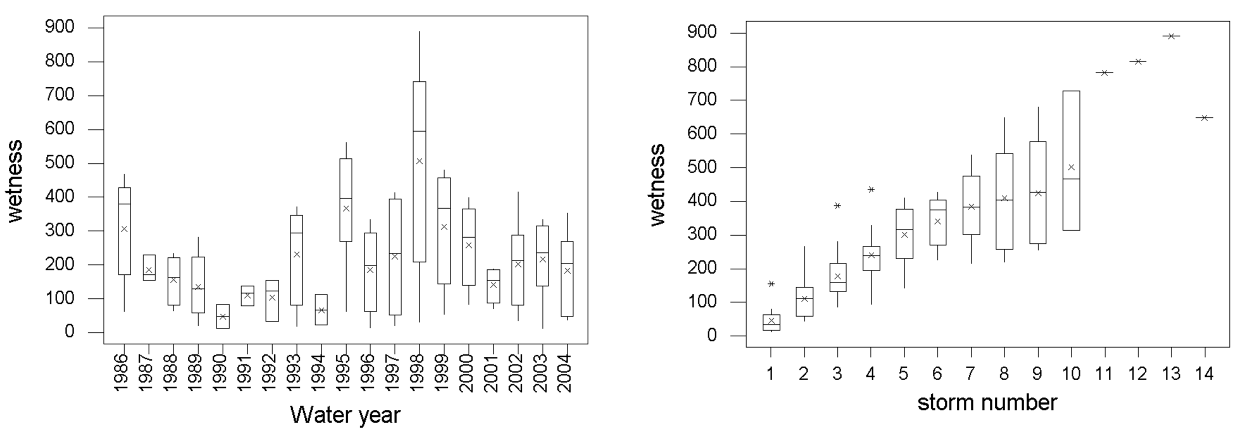


**Figure 3. Boxplots of wetness by water year and by storm number for each year.**

The peak flow model was developed from these storms and their associated antecedent wetness. No other variables related to roads, skid trails, landings, firelines, burning or herbicide application were found to improve the fit of the model (Lewis et al. 2001). The model for peak flow is mathematically represented by Equation 2 (PALCO, 2000) with the coefficients determined by the results of the experiment.

$$E(r) = \exp\{[1 + B_2(t-1)]c[B_4 + B_5 \ln(y_c) + B_6 \ln(w)]\}$$ **Equation 2**

Where:

*E(r)* = expected ratio between the observed flow and the expected flow without a logging effect in a watershed as a result of a storm (unitless ratio)
$B_2$ = logging recovery coefficient (-0.0771)
$B_4$ = vegetation reduction constant (1.1030)
$B_5$ = storm size coefficient (-0.0963)
$B_6$ = watershed wetness coefficient (-0.2343)
$y_c$ = mean of unit area peak flows at control watersheds HEN and IVE ($m^3\ s^{-1}\ ha^{-1}$)
$w$ = antecedent wetness (unitless parameter)
$c$ = proportion of watershed canopy removed (unitless ratio)
$t$ = time since harvest that calculation is made (years)

However, Lewis and Keppeler (in press) have refitted the model to all peak flows up to the time of the pre-commercial thinning. In doing so, the model's coefficients have changed slightly and are included in Table 1. The updated coefficients are used in all model runs in this report.

Table 1. Model coefficients for the peak flow model (Lewis and Keppeler, in press).

| Parameter | Effect | Estimate |
|---|---|---|
| $B_2$ | Recovery | -0.101 |
| $B_4$ | Vegetation reduction | 1.290 |
| $B_5$ | Storm size interaction | -0.110 |
| $B_6$ | Wetness interaction | -0.278 |

To determine increases in peak flow due to canopy removal, appropriate values must be determined for: time since harvest ($t$), the portion of watershed canopy removed as a ratio of removed acreage to watershed acreage ($c$), antecedent wetness ($w$), and the mean of the unit area peak flows at the control watersheds ($y_c$). Staff did not use the fall logging coefficients from Lewis and Keppeler (in press) in the application of the peak flow model, because fall logging information was not available.

Time since harvest ($t$) is determined from a watershed's harvest history. The results from Casper Creek indicate recovery in 10 – 12 years (Lewis and Keppeler, in press). The portion of watershed canopy removed ($c$) is based on the harvest history for the watershed, with consideration of silvicultural method. This parameter is calculated simply as the clearcut equivalent acres harvested in that year divided by the watershed area. The harvest acres were converted to clearcut equivalents by applying a weighting coefficient that reflects the proportion of canopy removed per silvicultural method (see Appendix).

Model sensitivity

It is important to understand the sensitivity of the Caspar Creek empirical peak flow model to changes in the input variables. By using the harvest history of North Fork Elk River, the sensitivity of the model's output to changes in the values of wetness and recurrence interval were evaluated.

It is important to look at the estimates of current conditions based on a range of values for both wetness and recurrence interval. As described earlier, wetness varies throughout the season.

Results from the Caspar Creek experiment showed that all recurrence interval streamflows were affected by harvest-related increases. Additionally, it is impossible to estimate when a particular recurrence interval event will occur; it could occur in any given year, under any given wetness index conditions.

Figure 4 demonstrates the effect that varying wetness has on estimation of peak flow increases in (a) 0.25-year, (b) 2-year, and (c) 15-year recurrence interval peak flows in North Fork Elk River. Recurrence intervals for the peak flow at the control watersheds ($y_c$) were determined from the partial duration series (Dunne and Leopold, 1978). While examining these figures, close attention should be paid to how the range of values for both wetness and recurrence interval affects the estimates for harvest related increases in peak flow. Figure 4(a) shows the flow increases for the minimum (10), first quartile (116), median (224), third quartile (356) and maximum (892) antecedent wetness. Figures 4(b) and 4(c) exclude the maximum wetness since it occurs outside of the range of observed values for these recurrence intervals and the model predicts negative values.

As shown in the above figures, lower wetness generates higher increases in peak flow. Shorter recurrence interval storms (i.e. storms that occur more often) have higher increases in peak flows. These figures also show that the model is more sensitive to wetness than recurrence interval. The sensitivity of the model to wetness also can be deduced by noting that the coefficient for the wetness ($B_6$) is 2.5 times more than the coefficient for recurrence interval ($B_5$).

Another important factor to remember is that the peak flow model is an exponential model. The natural logarithm of the wetness and expected peak flow are used as inputs when determining the increase in peak flow (Figure 5). There are large differences in the result of the natural logarithm at the lower end of the scale, particularly when the wetness is lower than 150. This result matches the observed increases in peak flow quite well since the largest increases in peak flow occur when the wetness is lower (i.e., when the watershed is drier, canopy removal exerts a larger influence on runoff). A similar result occurs with the natural logarithm of the peak flow at the control watersheds (i.e., there are larger relative increases in peak flow for smaller storms than with larger storms).

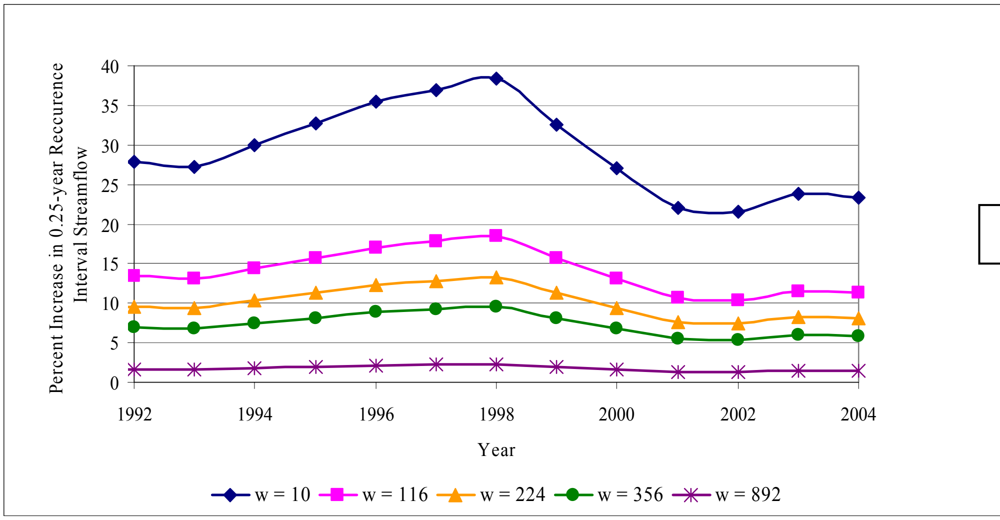


Figure 4a.

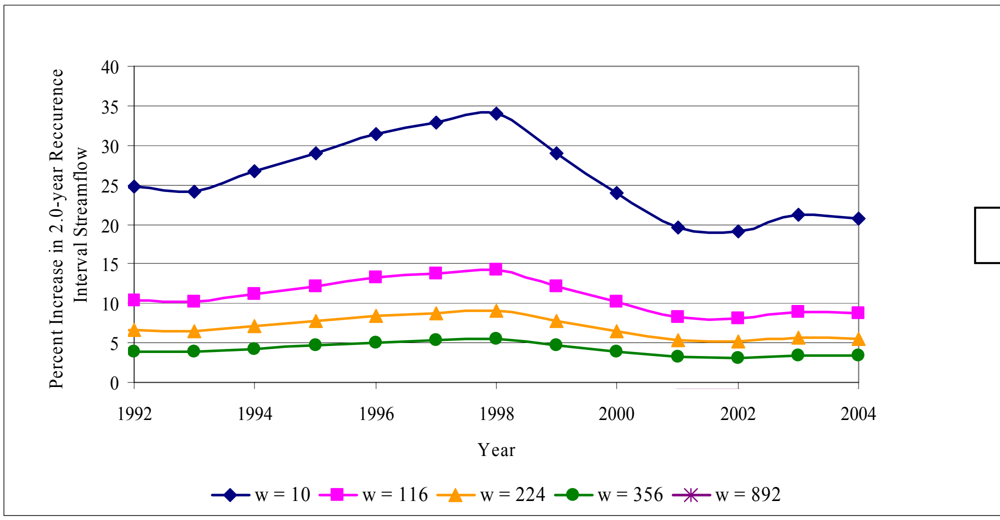


Figure 4b.

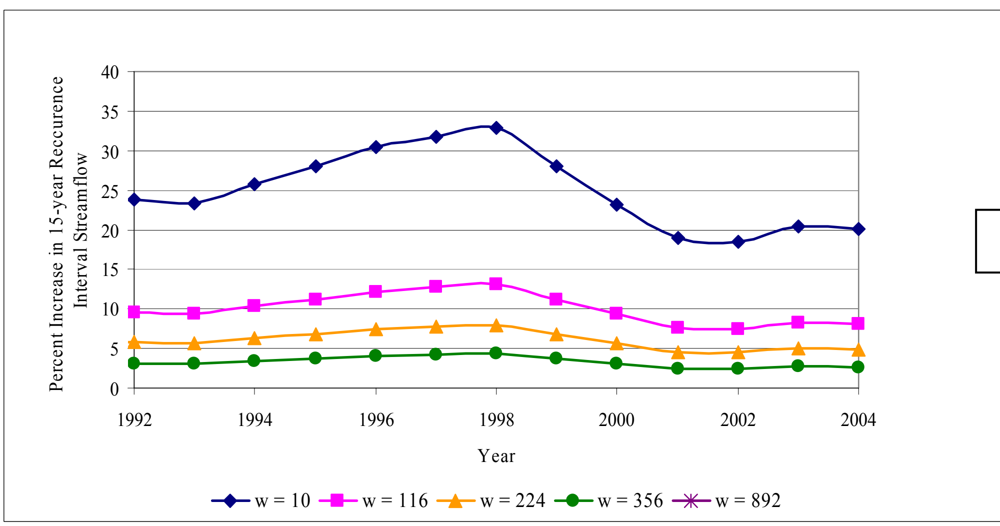


Figure 4c.

**Figure 4. The percent increase in the a) 0.25-year, b) 2-year and c) 15-year recurrence interval stream flows for the minimum (10), first quartile (116), median (224), third quartile (356) and maximum wetness (892) for North Fork Elk River watershed and its recent harvest history. Figures 4b and 4c don't chart the maximum wetness since the model predicts negative values.**

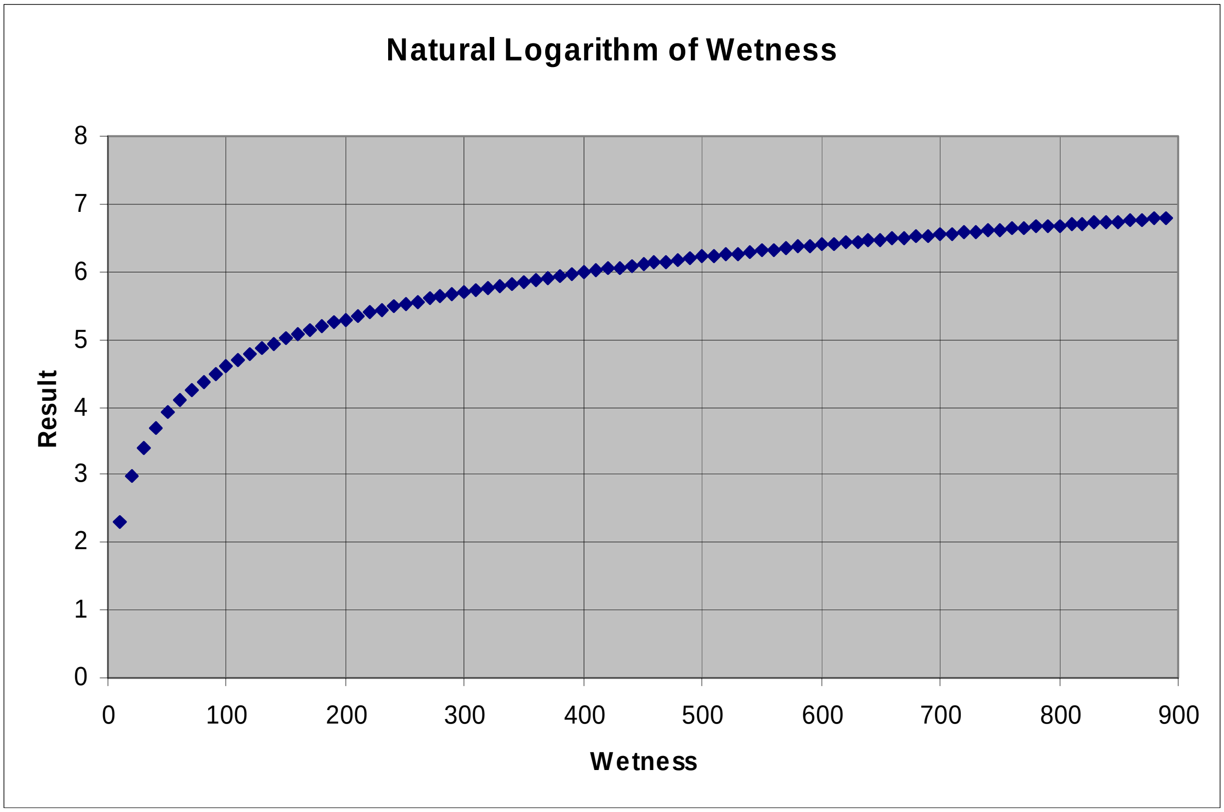


**Figure 5. The natural logarithm of the wetness. The peak flow model uses the natural logarithm of wetness as an input into the model.**

Table 2 summarizes estimated increases in peak flow in 2004 based on the harvest history in each of the subject watersheds.

**Table 2. Summary of the 2004 increases in peaks flows.**

| | | Percent Increase in Peak flows | | |
|---|---|---|---|---|
| Recurrence Interval | Wetness Index | North Fork Elk River | South Fork Elk River | Freshwater Creek |
| 0.25 | 10 | 23 | 9 | 25 |
| | 116 | 11 | 4 | 12 |
| | 224 | 8 | 3 | 9 |
| | 356 | 6 | 2 | 6 |
| | 892 | 1 | 1 | 2 |
| 2.0 | 10 | 21 | 8 | 23 |
| | 116 | 9 | 3 | 10 |
| | 224 | 6 | 2 | 6 |
| | 356 | 3 | 1 | 4 |
| | 892 | * | * | * |
| 15 | 10 | 20 | 8 | 22 |
| | 116 | 8 | 3 | 9 |
| | 224 | 5 | 2 | 5 |
| | 356 | 3 | 1 | 3 |
| | 892 | * | * | * |

* indicates that the values fall outside of the observed range

### *Application of Peak Flow Model to Freshwater Creek and Elk River*

Watershed differences that may affect the results of the peak flow model

When applying the peak flow model to other watersheds, it is important to keep in mind that differences in the watersheds may cause the model to over-predict or under-predict peak flow increases. There are two major differences between Caspar Creek and the target watersheds that may affect the predictions of the model for the target watersheds.

First, the Freshwater Creek and Elk River are much larger watersheds than Caspar Creek. Freshwater Creek is approximately 19,700 acres while the largest of the monitored watersheds on North Fork Caspar Creek is 1,170 acres; over sixteen times smaller. The differences in size will likely overestimate in peak flow increases.

The other major difference between Caspar Creek and the target watersheds are the extent and locations of roads and skid trails. The roads in Caspar Creek are all ridge roads that have no watercourse crossings. Caspar Creek had only 7.6% of the watershed harvested by tractors. The percent area in skid trails is 0.8%. This contrasts with the target watersheds, where there are numerous watercourse crossings, and where tractor harvesting has been conducted for over fifty years, which leaves a large network of skid trails in the watershed. Hence, there are large differences in effective watercourse network and compaction in the watershed which will likely underestimate in peak flow increases.

Procedure for model application

Several steps were taken to apply peak flow model to the Freshwater Creek and Elk River watersheds. Appropriate input parameters for the Caspar Creek empirical peak flow model were determined before the selection of targets. This included determining (1) the watershed area and harvest history, (2) peak flows ($y_c$) and recurrence interval, and (3) wetness.

Watershed area and harvest history

The geographic extents of the analyses are defined based upon a combination of factors, including watershed size, ownership, and land use, and location of nuisance flooding conditions. Staff determined that the appropriate watersheds in which to use the peak flow model are the Freshwater Creek, North Fork Elk River, and South Fork Elk River watersheds. Staff chose these watersheds because the harvest histories were available, but also because there is specific information allowing the calculation of the appropriate recurrence interval for nuisance conditions.

The North Fork and South Fork Elk River were evaluated separately, because 1) the model was developed from smaller watersheds, and 2) applying the model to the North Fork and South Fork separately acknowledges the differences in timber harvest intensity and land use (i.e., the large forested tract of the Headwaters Forest Reserve in the South Fork Elk River watershed). The WWDRs apply to lands in the upper three Freshwater Creek planning watersheds. The Howard Heights Bridge is the location chosen for defining nuisance. It is assumed that the recurrence interval of nuisance at the downstream extent of the three planning watersheds is comparable to that of Howard Heights.

When applying the peak flow model, staff considered three different options of watershed area and PALCO's harvest history for determining the portion of canopy removal ($c$). The options are: total watershed area and total harvest history, total watershed area and PALCO's harvest history, or PALCO's ownership and harvest history. While the two latter options may have advantages because the permit will only apply to PALCO, staff determined that using the total watershed area and harvest history is appropriate for this permit. This is because the estimated increases in peak flow could then be transformed to show increases in the flood stage height. The ability to convert percent increases in peak flow into stage height helps to determine an appropriate target for increases in peak flow. Examination of the harvest histories shows that other landowners have had minor amounts of timber harvest. It is anticipated that future canopy removal from other landowners will also be minor. When future timber harvest plans by other landowners are received, staff will consider if the General WDRs are appropriate.

Harvest histories were provided by PALCO (2004a and 2004b), Green Diamond Resource Company (2004), and CDF. The harvest histories consist of summaries of acreage under different silvicultural applications applied across the watershed landscape.

Peak flows ($y_c$) and the recurrence interval

As described above, the peak flow model estimates the percent increase in a specified peak flow. The partial duration series (Dunne and Leopold, 1978) is used to transform the peak flows at Caspar Creek into recurrence intervals. To apply the peak flow model for the Freshwater Creek and Elk River watersheds, the recurrence intervals for Caspar Creek are matched with the recurrence intervals for nuisance flooding. The target recurrence interval streamflow is the peak flow associated with nuisance flooding for the current conditions in the Freshwater Creek and Elk River watersheds. Nuisance flooding occurs at different recurrence intervals for locations where the model is applied.

The partial duration flood series is also useful for estimating stream flow and precipitation events of low recurrence interval from a short record. The partial duration series includes all flood peaks above a certain base magnitude. The base is usually chosen as equal to the lowest annual maximum flood of record. However, because we are interested in determining the lowest recurrence interval of stream flows resulting in nuisance conditions, we evaluated the partial duration series for stream flows in which specific locations are inundated as our base.

The recurrence interval based on the partial duration series was calculated per Equation 3.

$$RI = (n+1) / m \qquad \textbf{Equation 3}$$

Where,

$RI$ = recurrence interval of peak flow
$n$ = number of years in record
$m$ = rank of peak flow in record

Appropriate target recurrence intervals of peak flow events were evaluated. Peak flows that result in nuisance conditions to people were identified by:

1. identifying locations where nuisance occurs when area is inundated,

2. identifying the stage and associated discharge above which the identified location is inundated, and
3. evaluating available records to determine the recurrence interval of the stage and streamflow to inundate the location.

Once the recurrence interval for the nuisance flood event in the watershed is determined, the recurrence interval is used as a surrogate for the control peak flow ($y_c$).

### *Freshwater Creek*

The Howard Heights Bridge over Freshwater Creek on Howard Heights Road was chosen as the location for the application of the peak flow model because the nuisance flooding there is quite apparent and its frequency is quantifiable. The flooded section of road adjacent to the bridge limits residents' ingress and egress. Of particular use to the determination of recurrence intervals of nuisance flows is a record of dates for which the river floods at the bridge.

To determine the frequency of flooding at the Howard Heights Bridge, staff solicited records maintained by the residents of Howard Heights Road (Cook). In addition to the declaration, dates were reported to complete Hydrologic Year 2004 (Cook, 2004 & 2005).

**Table 3. Summary of flood events at Howard Heights Road bridge.**

**Hydrologic Year**

| **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
|---|---|---|---|---|---|
| 11/21 | 1/11 | | 12/5 | 12/14 & 15 & 16 | 12/13 & 14 |
| 11/23 | 1/14 | | 12/13 & 14 | 12/27 & 28 | 1/1 |
| 12/2 | 2/14 | | | 12/31 | 2/17 & 18 |
| 2/6 & 7 | | | | 2/19 | |
| 3/24 | | | | 3/26 | |
| | | | | 4/25 | |

From those data, the recurrence interval of flooding was calculated as 0.37 (2.7 times per year), with $n$ = 6 and $m$ = 19. For application in the Freshwater Creek watershed, the design recurrence interval stream flow was designated as: $RI$ = 0.4.

The basic assumptions to this calculation are:

1) The recurrence interval of nuisance at Howard Heights is similar to that of the bottom of the drainage area of the three planning watersheds. Howard Heights Bridge comprises 84% of the drainage area.
2) The record of the observed floods as submitted by the Cooks are complete and include all floods during the evaluated time period.
3) Floods occurring on sequential days were considered a single event. This assumption likely underestimated the total number of events, and likely yielded a higher (less frequent) recurrence interval for flooding of Howard Heights Bridge than actually occurs.

## *North Fork Elk River*

A key location affecting access and egress for residents of both North Fork and South Fork Elk River is immediately downstream of the North Fork Elk River Bridge and the intersection of Elk River Road and Wrigley Road.

Watershed Watch, a local volunteer watershed group, installed water level staff plates and began stream flow measurements in the North Fork Elk River in HY 2000. Both Watershed Watch and PALCO began continuous stage monitoring in North Fork Elk River in HY 2003. Stage-discharge relationships allow the stage (water level) to be converted into a continuous discharge[2] (stream flow) record, or hydrograph. The stage-discharge relationship developed by Watershed Watch for monitoring stations NFE (discharge measurements are made at Station NFE, located at the North Fork Elk River Bridge) and KRW (electronic stage measurements are made at Station KRW, located at 2550 Wrigley Rd) is displayed in Figure 6. The hydrographs for HYs 2003 and 2004 are displayed in Figure 7. These discharge records were used to determine the frequency, or recurrence interval of nuisance flooding through the partial duration series.

Regional Water Board staff conducted field surveys to determine the elevation of various points along the roadway to estimate the corresponding discharge that results in inundation of the roadway. The surveys was conducted from the south of the Elk River Road concrete bridge downstream to a small watercourse that enters North Fork Elk River along the right bank. The field survey and calculations are included in the Appendix.

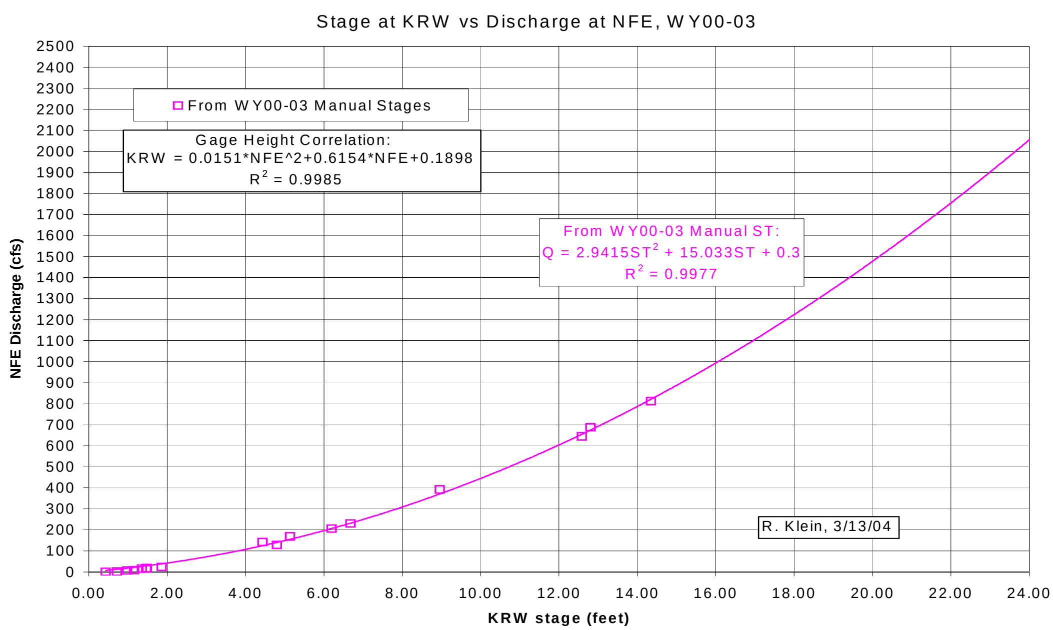


**Figure 6. Watershed Watch stage-discharge relationship and rating curve for the North Fork Elk River at the bridge located at the intersection of Elk River Road and Wrigley Road.**

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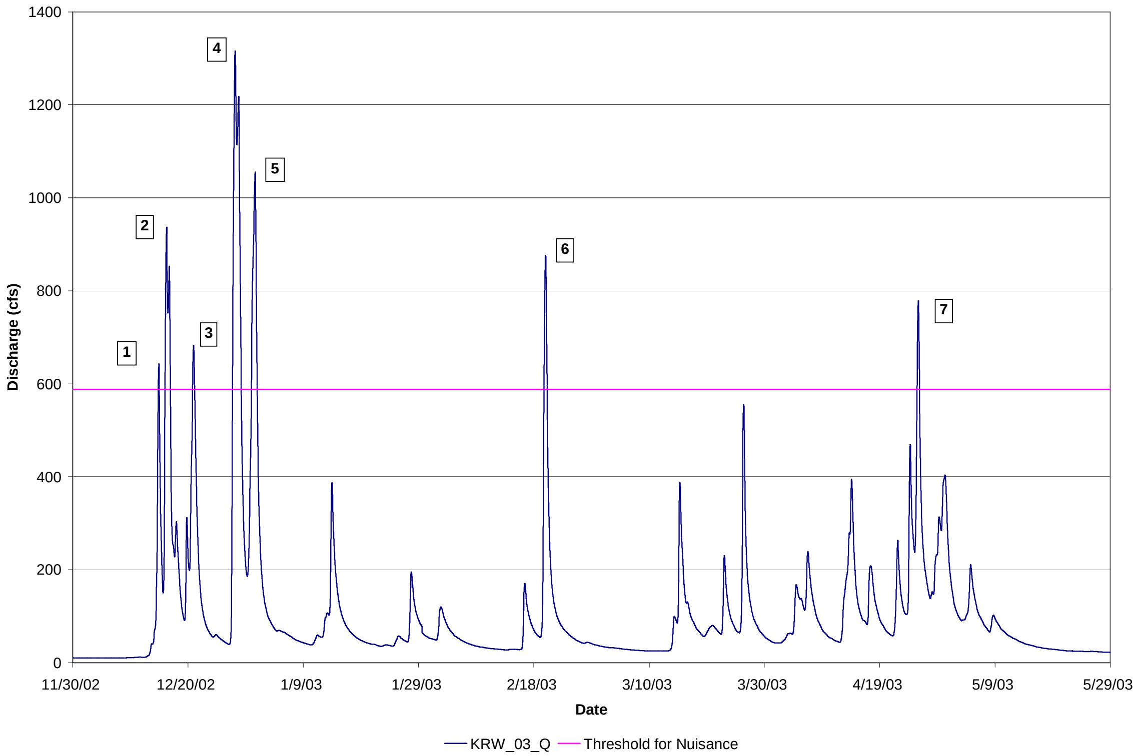
[2] The use of "discharge" is conventional in scientific discussions and is synonymous with stream flow rate. Its use in this report is in that context, and should not be confused with the use of the term "discharge" in a regulatory sense.

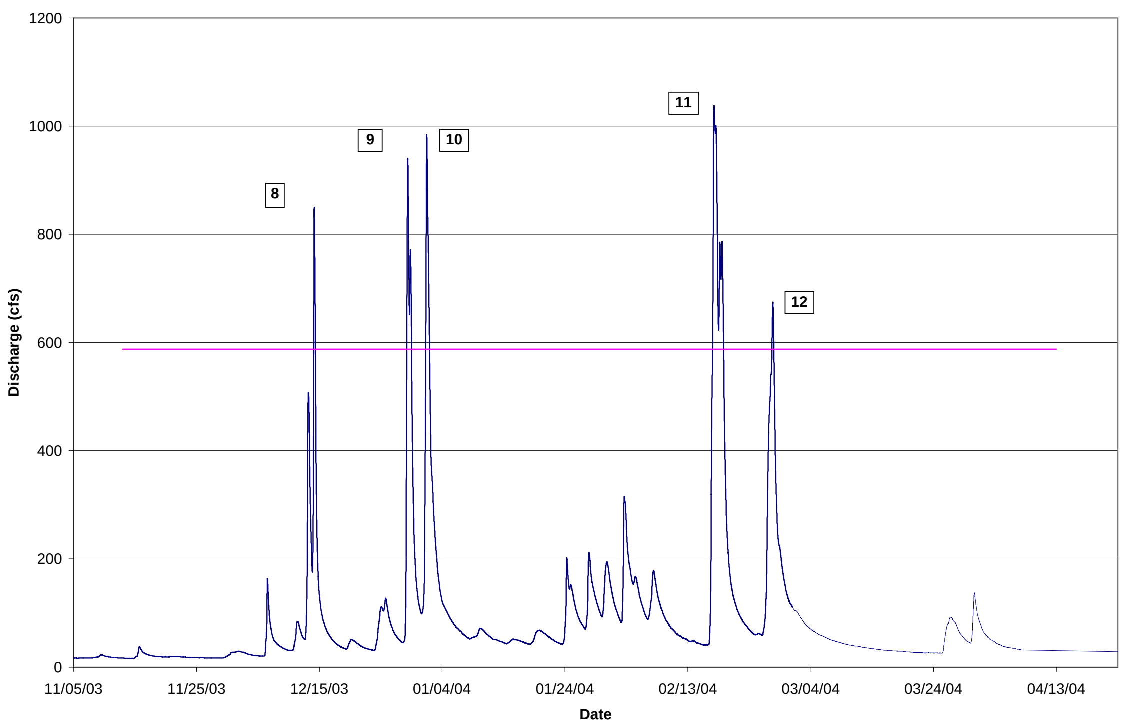
A culvert meant to drain the road surface along the river side of the road is inundated at a discharge of 466 cubic feet per second (cfs), becoming completely ineffective. A berm separates the road from the river, and a break in that berm is the first place water enters the road area (at 484 cfs) and reaches the river-side edge of the pavement (at 508 cfs.) At 588 cfs, water reaches the centerline of the roadway for a distance of approximately 35 feet. At 640 cfs, a 240-foot length of road is entirely covered with water depths up to 2 feet.

The hydrographs shown in Figure 7 indicate the number of storm events that reached the center of the pavement (flows greater than 588 cfs) for HY 2003 and 2004. The largest peaks in a 24-hour period greater than 588 were considered flooding events.

During HYs 2003 and 2004 ($n$ = 2), twelve peaks meeting the criteria were identified ($m$ = 12). The calculated recurrence interval of peak flow reaching the center of the pavement is 0.25 years (i.e., occurs 4.0 times per year) and was selected as the target recurrence interval associated nuisance flooding.

The primary limitation to this estimate is that only two years of data were available and therefore there is a fair amount of uncertainty associated with the estimated nuisance recurrence interval. The recurrence interval may change as additional years of data become available.




**<u>Figure 7.</u> Hydrographs for the North Fork Elk River for hydrologic year 2003 & 2004. Storms with peak flows that exceed the threshold are numbered.**

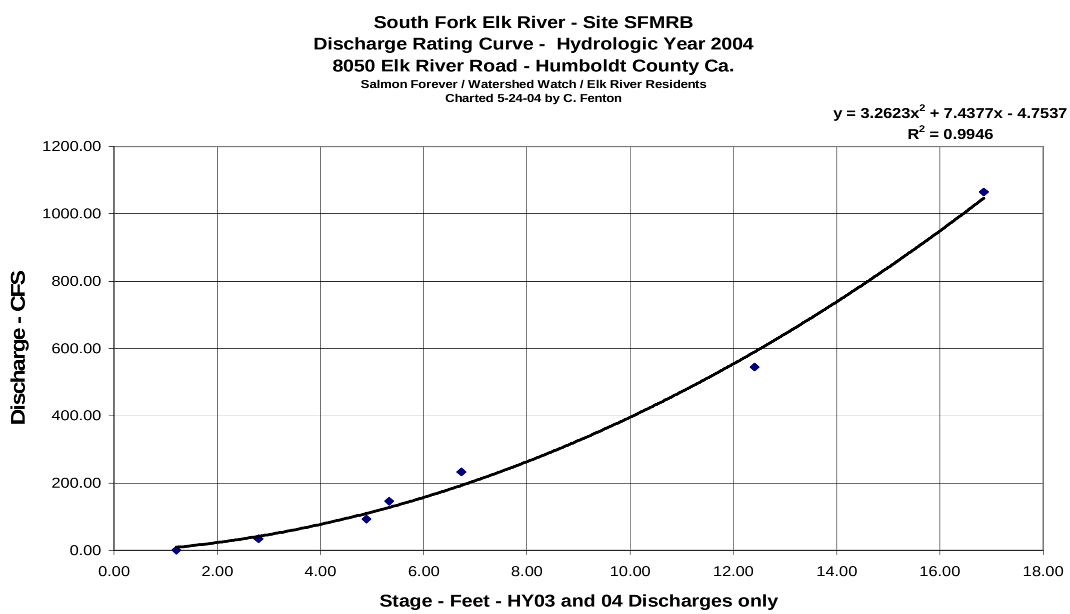
## *South Fork Elk River*

Nuisance at South Fork Elk River is not as well documented as on the North Fork Elk River. Staff has received complaints of channel filling, inundation of orchards and driveways, overtopping of recently retrofitted bridge deck, and water inundating the crawl space beneath homes and threatening to enter homes.

Watershed Watch installed staff plates and in HY 2001 began stream discharge measurements at 8050 Elk River Road (located on lower South Fork Elk River); they installed a continuous stage recorder in HY 2003.

Staff conducted a survey at 8050 Elk River Road to determine the elevation of various features, including the driveway, the floor levels of the existing buildings, and the level of concrete slabs which can cause damage to property when inundated. These elevations were tied into the stage-discharge relationship to determine the discharge required for inundation. The contemporary stage-discharge relationship is shown in Figure 8 below. Based upon the survey and the stage-discharge relationship, we determined that a discharge of 1,338 cfs results in access limitations at the residence surveyed on South Fork Elk River. However, only a single peak achieved this stream flow during the period of record for the HY 2003 and HY 2004 discharge records. This indicates that the nuisance event may occur at the same recurrence interval as bankfull events (events that occur every 1.5 to 2 years).

The short period of record limits the ability to estimate the frequency of nuisance flooding. Furthermore, staff only surveyed one residence and there may be another location where nuisance occurs at a lower stage height. In lieu of being able to determine the target recurrence interval based upon the above information, staff used a recurrence interval of 1.5 years as the input for the peak flow model.




**<u>Figure 8.</u> Watershed Watch's stage-discharge relationship and rating curve for South Fork Elk River.**

Wetness Selection

To help determine an appropriate antecedent wetness, we used the Monte Carlo approach to produce a random wetness distribution based on the Caspar Creek data, and to produce exceedance probability curves (PALCO, 2005a). However, some slight changes were made to PALCO's methodology.

First, we used the full distribution of antecedent wetness instead of discarding a portion of the distribution. PALCO (2005c) recommends discarding wetness values that occurred for storms with recurrence intervals less than the estimated nuisance recurrence interval (0.25 years for North Fork Elk River, 0.40 for Freshwater Creek).

As stated earlier, any recurrence interval event can occur at any time in the year. There are more meaningful ways to select a portion the antecedent wetness distribution. One approach is to remove the outliers of the observed wetness distribution (Figure 2). Another approach is to discard wetness values that are associated with storms that are larger than bankfull discharge (1.5 – 2.0 years), since these events generally overtop the stream banks and cause flooding in undisturbed watersheds.

Lisle, et al. (2000b) evaluated a wetness distribution with recurrence interval greater than 0.25 years when they conducted their analysis for the 2-year recurrence interval flow. CDF (Munn 2001, 2002) used the same dataset as Lisle, et al., for their analysis.

Staff evaluated all these scenarios, which in effect would increase or decrease the median and mean of the distribution. A significant concern is that there is a limited amount of flow data in these watersheds at the nuisance locations to determine the nuisance recurrence interval. Therefore, given this uncertainty, we find it reasonable to include the full data range when conducting the analysis. Furthermore, since the nuisance recurrence interval used in this analysis is much smaller than the recurrence interval used in previous efforts (Lisle, et al. 2000b and Munn 2001, 2002), it is appropriate to use the full distribution of antecedent wetness even though a portion of the distribution occurs at recurrence intervals less than the target interval.

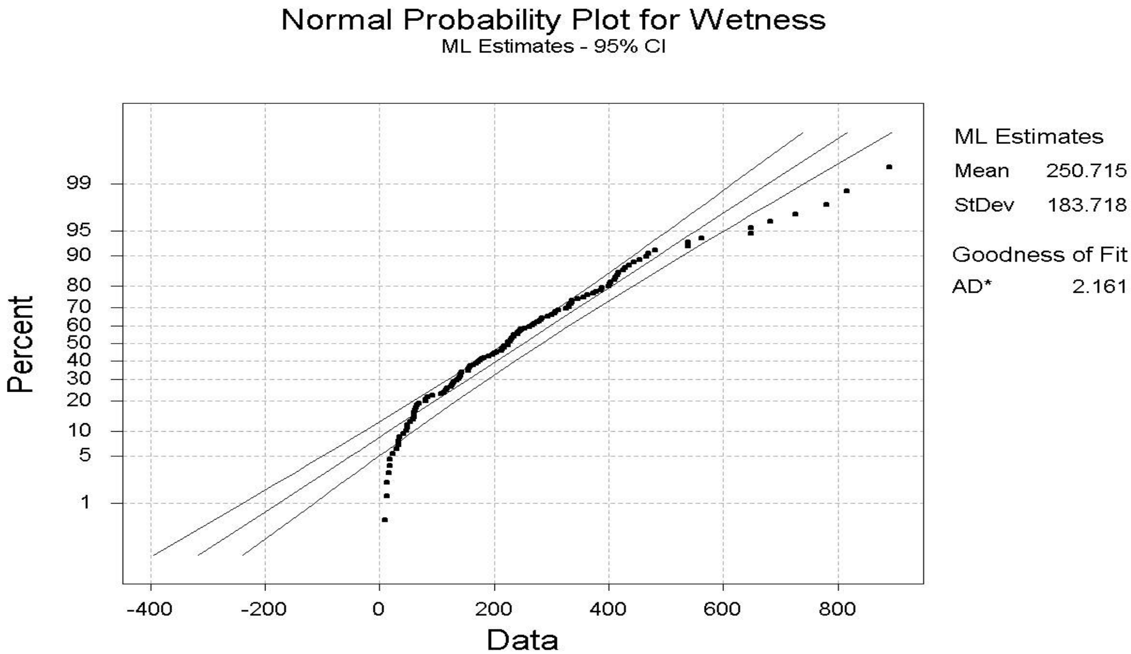
Second, when producing a random distribution, PALCO (2005c) recommends using a normal distribution for the wetness distribution. We chose to use the Weibull distribution for several reasons, including the fact that observed wetness distribution is not normal, but skewed to the right. There are several physical reasons for this. First, the wetness index is based on accumulations of daily mean flow. Daily mean flow is not normally distributed, therefore there is little reason to suspect that the wetness index is normally distributed. Second, the wetness index is bounded by zero (there can be no negative values) at the lower end of the distribution. Normal distributions have a non-zero probability for all values (i.e., they are unbounded).

We used the adjusted Anderson-Darling statistic from MINITAB® statistical software to determine the goodness-of-fit for several distributions for both maximum likelihood and the least squares methods. The observed antecedence wetness was compared to normal, lognormal, Weibull, and other distributions. The Weibull distribution had the lowest Anderson-Darling statistic (0.486 compared with 2.161 for normal distribution and 2.731 for lognormal distribution), indicating that the Weibull distribution is the best fit. Probability plots were produced using MINITAB® and are shown in Figure 9 for the normal distribution and the Weibull distribution. As shown in the figure, the Weibull distribution not only fits the data better in the tails of the distribution and only has one data point outside the 95% confidence intervals, but also is closer to the fitted line than the normal distribution.

Normality tests were conducted for the antecedent wetness using both the Kolmogorov-Smirnov test and the Anderson-Darling test. The P-values were $< 0.01$ and 0.000 respectively, which indicate the null hypothesis that the data follow a normal distribution is rejected (i.e., the observed antecedent wetness distribution is not normally distributed).

It is important to note that if a normal distribution was used, it would significantly underestimate the frequency of observed antecedent wetness values in the lower end of the distribution. This has a significant affect on the peak flow model's distribution and it will under-predict increases in peak flow. (The exceedance probability chart for both the normal distribution and the Weibull distribution is shown in Figure 10.) Therefore, for these reasons, we used a Weibull distribution when we generated a random wetness distribution for the Monte Carlo simulation.

In order to determine an appropriate antecedent wetness index for applying the peak flow model in these watersheds, we take guidance from the Clean Water Act. Clean Water Act section 303(d)(C) states "Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The Total Maximum Daily Load (TMDL) regulations mirror this language, and state that "determinations of TMDLs shall take into account critical conditions for stream flow, loading and water quality parameters." (40 CFR §130.7 (c)(1)). Since the greatest increases in peak flow occur when the watershed is the driest (i.e., when there is a low wetness), we examined the exceedance probability chart (Figure 10) and the storm number boxplot (Figure 3) to determine an appropriate value for the antecedent wetness. Figure 3 shows that the critical conditions for peak flows occur within the first several storms of the hydrologic year.



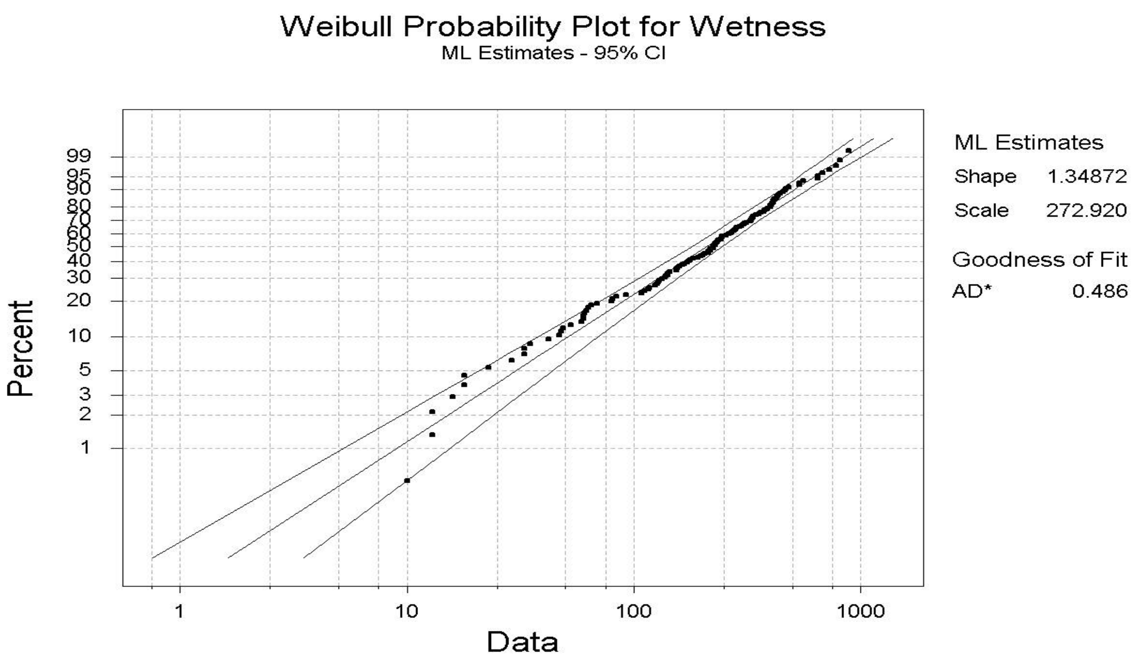




**Figure 9. Probability plots for the observed antecedent wetness distribution.**

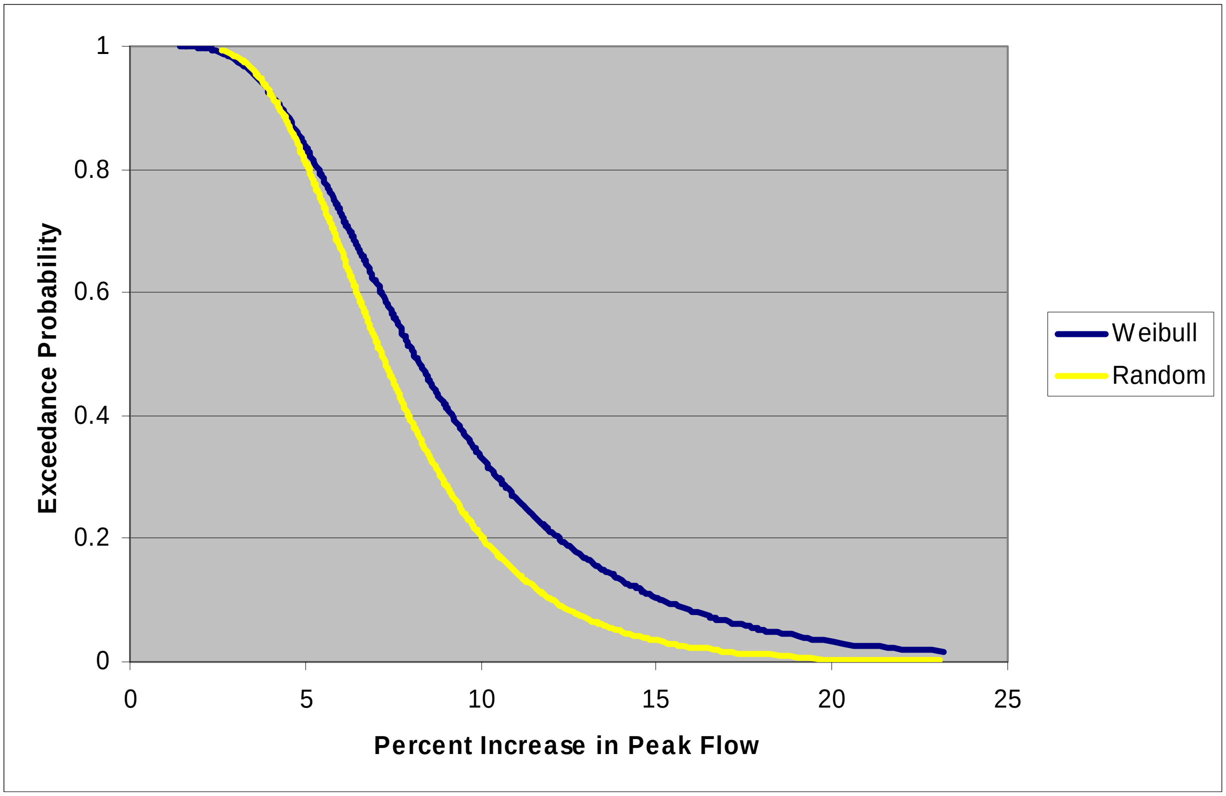



**Figure 10. Exceedance probability for predicted increases in peak flow for North Fork Elk River.**

Staff determined that an antecedent wetness that corresponds to an exceedance probability of 0.33 is appropriate for this permit, which includes a margin of safety and accounts for critical conditions. In essence, the exceedance probability of 0.33 means that one out of three times there is a likelihood of under-predicting increases in peak flow. The corresponding antecedent wetness for this exceedance probability is 150 and represents a 10% increase in peak flows for North Fork Elk River for harvesting through 2004. This value is within the range of observed wetness for November and December storms (10 - 326) and is above the mean wetness for November (26) and December (110). Figure 3 shows that an antecedent wetness of 150 is higher than the median for the first two storms (33 and 112 respectively) and is between the median and first quartile of the third storm. This wetness is used for all three watersheds.

In an effort to evaluate the appropriate value of and means of calculating the wetness index, Lisle et al. (2000b) evaluated Caspar Creek flows with recurrence interval greater than 0.25 years and found that approximately 6% of the 2-year recurrence interval stream flows are expected to occur at the minimum wetness index ($w$=50). CDF's application of the peak flow model used several wetness values; the mean wetness for storms greater than 0.25 recurrence interval (304 as published by Lisle et al. 2000b) as well as 50 and 400. It is interesting to note that for CDF's stated goal of determining a canopy removal rate that will not result in an increase in peak flow over current conditions, the choice of antecedent wetness is insensitive to this goal. As long as the future harvests are equal to or less than average harvests of the last 11 years, the goal of no increase in peak flows is met.

PALCO (2005c) recommends using the mean antecedent wetness for a distribution that is higher than the target interval (e.g., ≥ 0.25 recurrence interval for North Fork Elk River). We chose not to use this wetness index because it doesn't allow for a margin of safety, nor does it account for critical conditions. In fact, because the wetness distribution is skewed to the right (and not normally distributed) and because there are larger increases in peak flow during drier watershed conditions, the average wetness produces an increase in peak flow that is smaller than the median wetness, which in turn is smaller than the average increase in peak flow.

### *Selection of Targets for Application of the Peak Flow Model*

To apply the peak flow model to these watersheds and to reduce some of the current nuisance conditions, two additional targets must be determined: the allowable percent increase in peak flows, and the timeframe to reach that goal. To help determine these targets, several canopy removal scenarios were evaluated, including the most-rapid (no harvest), 10-years, and 20-years for the three watersheds for the recurrence interval (0.4, 0.25, and 1.5 for Freshwater Creek, North Fork Elk River and South Fork Elk River respectively) with antecedent wetness of 150. These scenarios are shown in Figures 11 and 12. For Elk River, the charts show a proportional split of CDF's harvest limit among North Fork, South Fork, and the main stem of Elk River.

Since the application of the peak flow model by Lisle et al (2000b) and CDF (Munn 2001, 2002) have different goals, there are no recommendations for an allowable increase in peak flow. PALCO (2005c) states that they are still working on an allowable increase and design storm targets.

We set the allowable increase in peak flow at 5% to allow some recovery from the nuisance conditions in the Freshwater Creek and North Fork Elk River watersheds. For North Fork Elk River, if nuisance were considered at 588 cfs where one lane is blocked with floodwaters, the current estimated peak flow increase of 10% (at a wetness of 150) would be reduced by approximately 30 cfs, which would lower the floodwaters by approximately three inches. Since the probability of this increase in peak flows in 0.33, potentially a third of the time the decrease in peak flow would be more than this amount when the 5% target is reached.

For Freshwater Creek, at a ten-year trajectory to meet this target would allow 269 acres of clearcut canopy removal per year. For North Fork Elk River, a ten-year time period would allow 187 acres of clearcut canopy removal per year. Figure 11 also shows that a "no harvest" scenario would allow the 5% target to be reached in three years.

Figure 12 shows that the target level for South Fork Elk River is already below 5%. Since the 5% target is already met, it is recommended to maintain the current peak flow situation. This would allow for 131 acres of clearcut canopy removal per year in the watershed.

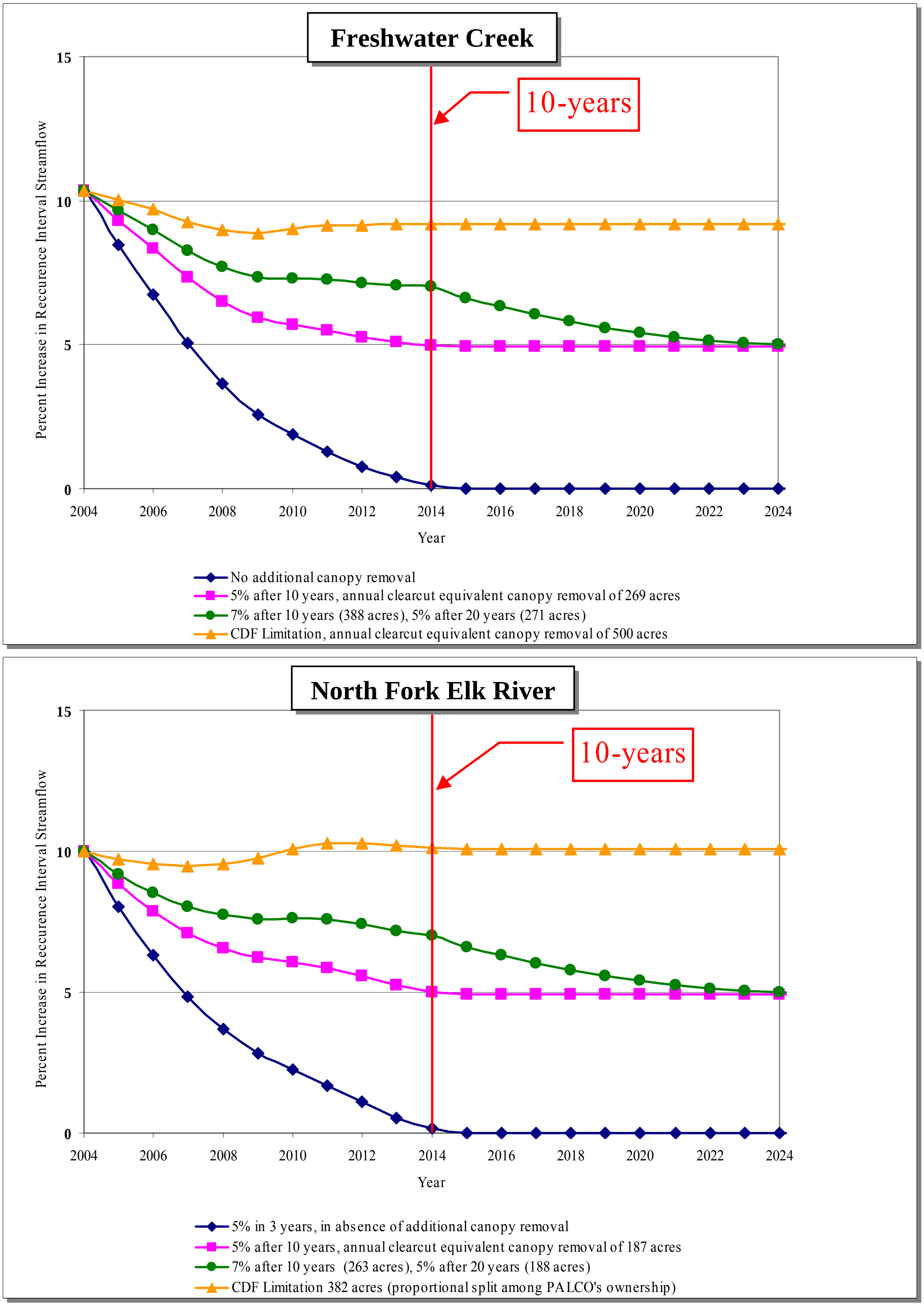



**Figure 11. Peak flow increases over the next 20 years based on a variety of future canopy removal scenarios for Freshwater Creek, and North Fork Elk River.**

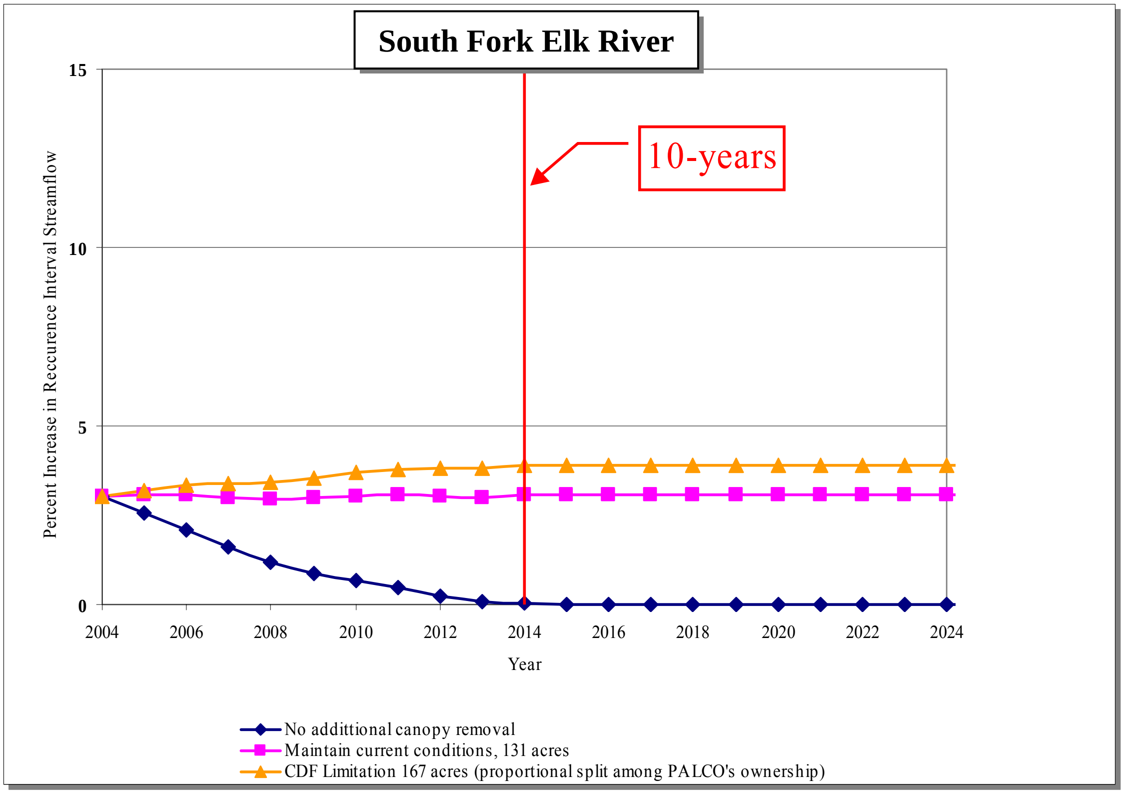



**Figure 12. Peak flow increases over the next 20 years based on a variety of future canopy removal scenarios for South Fork Elk River.**

### *Discussion*

The peak flow model is the best available for assessing contribution of canopy removal to increases in peak flows. As with all modeling exercises, there are assumptions, limitations, and uncertainties within the model and its application. These are discussed throughout the report with the key issues highlighted below.

First, two key differences between the Caspar Creek watershed and the target watersheds are their size and road (including skid trails) density and location. Although the size difference between the watersheds will likely lead to an overestimation in peak flows, staff believe this is balanced by the underestimation in peaks flows caused by the differences in road density and location.

Second, the application of the model in this report uses the best available information in determining the input parameters. However, there is some uncertainty associated with the input parameters, particularly with the recurrence interval associated with the current nuisance flooding. As further information on the stage-discharge relationship becomes available, or if there are dramatic changes in the channel capacity, (e.g., channel scour or aggradation, dredging or other reasons) the recurrence interval associated with nuisance flooding will likely change and should be reevaluated.

The Regional Water Board staff's application of the peak flow model builds upon CDF's application of the peak flow model in Freshwater Creek and Elk River. We determined the frequency of nuisance flood events in these watersheds while CDF defaulted to the 2-year recurrence interval peak flow when no watershed specific information was available. Furthermore, instead of maintaining the current nuisance conditions, we allow for some recovery from the nuisance conditions in these watersheds.

Lisle et al (2000b) employed a wetness of 50 when they evaluated the increases in peak flow for the Freshwater Creek watershed. CDF (Munn 2001, 2002) employed several values for wetness (50, 304 and 400) to show that their goal of not allowing further increases is met. Regional Water Board staff recommends a wetness value 150 for use in the WWDRs. This value considers critical conditions during the hydrologic year and provides a margin of safety while allowing timber harvesting to continue in these watersheds.

### *Modeling Results*

Freshwater Creek

Table 4 summarizes the recommended input values for the application of the peak flow model and the resulting clear cut equivalent acres of canopy removal per year for Freshwater Creek.

**Table 4. Selected input variable values.**

| **Geographic Extent** | Freshwater Creek<br>Planning watersheds: Cloney Gulch, Little Freshwater, Upper Freshwater |
|---|---|
| **Drainage Area** | 19,688 acres |
| **Harvest History** | Based on year harvested<br>*Data source: PALCO, CDF* |
| **Recurrence Interval** | 0.4<br>*Based on record of floods at Howard Heights* |
| **Recovery Threshold** | 5% |
| **Recovery time** | 10 years |
| **Annual Clearcut Equivalent Canopy Removal** | 269 acres |

North Fork Elk River

Table 5 summarizes the recommended input values for the application of the peak flow model and the resulting clear cut equivalent acres of canopy removal per year for North Fork Elk River.

**Table 5. Selected input variable values.**

| **Geographic Extent** | North Fork Elk River<br>Planning watersheds: Upper North Fork, Lower North Fork |
|---|---|
| **Drainage Area** | 14,435 acres |
| **Harvest History** | Based on year harvested<br>*Data source: PALCO, CDF* |
| **Recurrence Interval** | 0.25<br>*Based on record of floods at NFE*[3] |
| **Recovery Threshold** | 5% |
| **Recovery time** | 10 years |
| **Annual Clearcut Equivalent Canopy Removal** | 187 acres |

South Fork Elk River

Table 6 summarizes the recommended input values for the application of the peak flow model and the resulting clear cut equivalent acres of canopy removal per year for South Fork Elk River.

**Table 6. Selected input variable values.**

| **Geographic Extent** | South Fork Elk River<br>Planning watersheds: Upper South Fork, Lower South Fork |
|---|---|
| **Drainage Area** | 12,442 acres |
| **Harvest History** | Based on year harvested<br>*Data source: PALCO, CDF* |
| **Recurrence Interval** | 1.5<br>*Based on an assumption and nuisance complaints* |
| **Recovery goal** | Maintain current conditions |
| **Recovery time** | - |
| **Annual Clearcut Equivalent Canopy Removal** | 131 acres |

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[3] Monitoring Station NFE is located at the intersection of Elk River Road and Wrigley Road on North Fork Elk River, approximately 0.25 stream miles upstream of the confluence with South Fork Elk River.

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## *Appendix*

Information from the following tables was used in the modeling explained in the text of the report. Those data are presented in four tables:

Table 7. Wetness, streamflow and recurrence interval for storms from Caspar Creek.

Table 8. Canopy removal coefficients used to calculate clearcut equivalent acreages from harvest history.

Table 9. Timber harvest history in Freshwater Creek and the North and South forks of Elk River expressed as clearcut equivalent acres.

Table 10. Survey data from Elk River Road.

**Table 7. Wetness, streamflow and recurrence interval for storms from Caspar Creek.**

| storm | startdate | wetness | HI peak (m3/s/ha) | rank | RI (years) |
|---|---|---|---|---|---|
| 18 | 881220 | 59 | 0.000536 | 123 | 0.163 |
| 19 | 890108 | 130 | 0.000603 | 122 | 0.164 |
| 122 | 040216 | 270 | 0.000658 | 121 | 0.165 |
| 119 | 031228 | 134 | 0.000687 | 120 | 0.167 |
| 42 | 940122 | 23 | 0.000767 | 119 | 0.168 |
| 28 | 910323 | 117 | 0.000781 | 118 | 0.169 |
| 30 | 920210 | 33 | 0.0007825 | 117 | 0.171 |
| 29 | 910325 | 138 | 0.0008085 | 116 | 0.172 |
| 33 | 921208 | 16 | 0.000888 | 115 | 0.174 |
| 52 | 951211 | 13 | 0.0009275 | 114 | 0.175 |
| 27 | 910319 | 80 | 0.000984 | 113 | 0.177 |
| 39 | 930219 | 331 | 0.001058 | 112 | 0.179 |
| 20 | 890304 | 93 | 0.001198 | 111 | 0.180 |
| 36 | 930106 | 246 | 0.0013215 | 110 | 0.182 |
| 99 | 011128 | 33 | 0.0013834 | 109 | 0.183 |
| 2 | 860129 | 128 | 0.001415 | 108 | 0.185 |
| 68 | 980103 | 178 | 0.001426 | 107 | 0.187 |
| 64 | 970120 | 387 | 0.0014565 | 106 | 0.189 |
| 67 | 971214 | 159 | 0.001459 | 105 | 0.190 |
| 103 | 011216 | 228 | 0.0014925 | 104 | 0.192 |
| 89 | 990410 | 466 | 0.001497 | 103 | 0.194 |
| 114 | 030412 | 218 | 0.001554 | 102 | 0.196 |
| 8 | 860311 | 444 | 0.0015675 | 101 | 0.198 |
| 25 | 900521 | 49 | 0.001571 | 100 | 0.200 |
| 87 | 990228 | 482 | 0.001576 | 99 | 0.202 |
| 16 | 880108 | 235 | 0.0016065 | 98 | 0.204 |
| 1 | 860114 | 60 | 0.0016415 | 97 | 0.206 |
| 40 | 930222 | 364 | 0.0016615 | 96 | 0.208 |
| 10 | 870212 | 155 | 0.001672 | 95 | 0.211 |
| 102 | 011213 | 197 | 0.0017265 | 94 | 0.213 |
| 94 | 000229 | 401 | 0.0017325 | 93 | 0.215 |
| 85 | 990218 | 403 | 0.0017375 | 92 | 0.217 |
| 112 | 030215 | 275 | 0.0017435 | 91 | 0.220 |
| 9 | 860315 | 470 | 0.0017795 | 90 | 0.222 |
| 96 | 010222 | 141 | 0.0018115 | 89 | 0.225 |
| 12 | 870311 | 230 | 0.001901 | 88 | 0.227 |
| 17 | 881121 | 18 | 0.0019165 | 87 | 0.230 |
| 60 | 961204 | 18 | 0.001922 | 86 | 0.233 |
| 31 | 920218 | 124 | 0.001944 | 85 | 0.235 |
| 34 | 921210 | 47 | 0.0019755 | 84 | 0.238 |
| 117 | 031212 | 35 | 0.001985 | 83 | 0.241 |
| 97 | 010224 | 168 | 0.0020225 | 82 | 0.244 |
| 56 | 960120 | 224 | 0.002024 | 81 | 0.247 |
| 41 | 930316 | 294 | 0.002037 | 80 | 0.250 |
| 51 | 950321 | 563 | 0.002051 | 79 | 0.253 |
| 15 | 880102 | 182 | 0.0020545 | 78 | 0.256 |
| 118 | 031213 | 48 | 0.002091 | 77 | 0.260 |
| 123 | 040225 | 356 | 0.0021035 | 76 | 0.263 |
| 86 | 990224 | 454 | 0.002106 | 75 | 0.267 |
| 90 | 000115 | 81 | 0.0021135 | 74 | 0.270 |
| 113 | 030314 | 213 | 0.002114 | 73 | 0.274 |
| 98 | 010304 | 191 | 0.002126 | 72 | 0.278 |
| 7 | 860309 | 410 | 0.0021475 | 71 | 0.282 |
| 115 | 030423 | 254 | 0.002187 | 70 | 0.286 |
| 3 | 860213 | 214 | 0.002199 | 68 | 0.294 |
| 58 | 960218 | 306 | 0.002199 | 69 | 0.290 |
| 59 | 960220 | 337 | 0.002257 | 67 | 0.299 |
| 24 | 900106 | 13 | 0.0023195 | 66 | 0.303 |
| 121 | 040202 | 234 | 0.0023275 | 65 | 0.308 |
| 54 | 960115 | 127 | 0.002343 | 64 | 0.313 |
| 107 | 021213 | 10 | 0.0023445 | 63 | 0.317 |
| 23 | 890323 | 284 | 0.0023705 | 62 | 0.323 |
| 62 | 961229 | 224 | 0.002378 | 61 | 0.328 |
| 76 | 980216 | 782 | 0.0023955 | 60 | 0.333 |
| 65 | 970124 | 415 | 0.0024095 | 59 | 0.339 |
| 6 | 860307 | 379 | 0.0024155 | 58 | 0.345 |
| 81 | 990122 | 108 | 0.0024415 | 57 | 0.351 |
| 43 | 940216 | 112 | 0.002523 | 56 | 0.357 |
| 11 | 870304 | 172 | 0.0025875 | 55 | 0.364 |
| 55 | 960118 | 175 | 0.002594 | 54 | 0.370 |
| 80 | 981202 | 53 | 0.0025955 | 53 | 0.377 |
| 32 | 920314 | 155 | 0.002602 | 52 | 0.385 |
| 46 | 950126 | 388 | 0.002616 | 51 | 0.392 |
| 105 | 020106 | 417 | 0.0026745 | 50 | 0.400 |

| | | | | | |
|---|---|---|---|---|---|
| 21 | 890308 | 141 | 0.002763 | 49 | 0.408 |
| 74 | 980202 | 683 | 0.0027705 | 48 | 0.417 |
| 47 | 950130 | 436 | 0.002833 | 47 | 0.426 |
| 37 | 930113 | 300 | 0.0028565 | 46 | 0.435 |
| 92 | 000222 | 282 | 0.002865 | 45 | 0.444 |
| 100 | 011201 | 63 | 0.002913 | 44 | 0.455 |
| 50 | 950320 | 539 | 0.0029565 | 43 | 0.465 |
| 5 | 860218 | 412 | 0.003097 | 42 | 0.476 |
| 95 | 010219 | 69 | 0.003197 | 41 | 0.488 |
| 22 | 890317 | 224 | 0.0032195 | 40 | 0.500 |
| 75 | 980205 | 728 | 0.0033475 | 39 | 0.513 |
| 108 | 021215 | 60 | 0.0033905 | 38 | 0.526 |
| 73 | 980128 | 650 | 0.003573 | 37 | 0.541 |
| 13 | 871204 | 62 | 0.003651 | 36 | 0.556 |
| 110 | 021230 | 326 | 0.0036795 | 35 | 0.571 |
| 106 | 020219 | 232 | 0.003747 | 34 | 0.588 |
| 84 | 990216 | 334 | 0.0039735 | 33 | 0.606 |
| 93 | 000225 | 331 | 0.0039875 | 32 | 0.625 |
| 116 | 030428 | 313 | 0.004067 | 31 | 0.645 |
| 101 | 011205 | 139 | 0.004223 | 30 | 0.667 |
| 71 | 980116 | 430 | 0.0043345 | 29 | 0.690 |
| 91 | 000211 | 201 | 0.00441 | 28 | 0.714 |
| 82 | 990206 | 156 | 0.0046315 | 27 | 0.741 |
| 53 | 951229 | 42 | 0.0047115 | 26 | 0.769 |
| 77 | 980219 | 817 | 0.0047335 | 25 | 0.800 |
| 70 | 980114 | 347 | 0.004776 | 24 | 0.833 |
| 14 | 871208 | 144 | 0.0049305 | 23 | 0.870 |
| 66 | 971126 | 29 | 0.00501 | 22 | 0.909 |
| 48 | 950308 | 278 | 0.0051305 | 21 | 0.952 |
| 78 | 980221 | 892 | 0.0052785 | 20 | 1.000 |
| 111 | 030112 | 336 | 0.005588 | 19 | 1.053 |
| 83 | 990208 | 242 | 0.00566 | 18 | 1.111 |
| 35 | 921230 | 116 | 0.005852 | 17 | 1.176 |
| 120 | 031231 | 205 | 0.0060875 | 16 | 1.250 |
| 69 | 980111 | 218 | 0.006727 | 15 | 1.333 |
| 104 | 020101 | 307 | 0.006887 | 14 | 1.429 |
| 44 | 950106 | 61 | 0.0071235 | 13 | 1.538 |
| 26 | 900526 | 84 | 0.007482 | 12 | 1.667 |
| 57 | 960124 | 262 | 0.007554 | 11 | 1.818 |
| 45 | 950111 | 267 | 0.007563 | 10 | 2.000 |
| 109 | 021227 | 164 | 0.007658 | 9 | 2.222 |
| 72 | 980125 | 540 | 0.008343 | 8 | 2.500 |
| 4 | 860215 | 245 | 0.008535 | 7 | 2.857 |
| 79 | 980321 | 649 | 0.0087095 | 6 | 3.333 |
| 88 | 990324 | 426 | 0.009579 | 5 | 4.000 |
| 63 | 961230 | 242 | 0.0100045 | 4 | 5.000 |
| 61 | 961208 | 65 | 0.0100825 | 3 | 6.667 |
| 49 | 950313 | 404 | 0.0103465 | 2 | 10.000 |
| 38 | 930119 | 374 | 0.011487 | 1 | 20.000 |

Silvicultural coefficients

Table 8. Canopy removal coefficients used to calculate clearcut equivalent acreages from harvest history.

| Silviculture | Coefficient |
|---|---|
| Clearcut<br>Right-of-way<br>Rehabilitation<br>AP1[1] | 1 |
| Shelterwood Removal<br>Shelterwood Step<br>Seedtree Removal<br>Seedtree Step<br>Salvage<br>AP2[2]<br>AP3[3]<br>A4[4] | 0.75 |
| Selection<br>Commercial Thin<br>Thin<br>AP5[5]<br>HCP3[6] | 0.5 |

[1] Clearcut
[2] Seed Tree Seed Step (maintain 15 $ft^2$ basil area per acre, maximum 150' spacing between trees)
[3] Seed Tree Removal/Shelterwood Removal Step (Remove no more than 50 $ft^2$ basil area per acre/Remove no more than 100 $ft^2$ basil area per acre
[4] Seed Tree Removal/Shelterwood Removal Step (Remove no more than 50 $ft^2$ basil area per acre/Remove no more than 100 $ft^2$ basil area per acre)
[5] Shelterwood Step (retain at least 30 $ft^2$ basil area per acre)
[6] Maximum removal of 1/3 conifer basal area per 200 linear feet of Class III watercourse; Thinning will be distributed across all diameter classes; The site will be recaptured within 5 to 10 years; and, All sub and non-merchantable conifers will be left standing onsite if feasible. (Interim HCP measures, 6.3.4.1.4, bullet 16 & 17)
Note: Harvest areas employing the Variable Retention silvicltural prescription were calculated as a combination of clearcut and selection, with the retention areas being calculated as selection.

Harvest History

The harvest history data utilized for Freshwater Creek, North Fork Elk River, and South Fork Elk River are detailed in the following table.

**<u>Table 9.</u> Timber harvest history in Freshwater Creek and the North and South forks of Elk River expressed as clearcut equivalent acres.**

| Year of Harvest | Freshwater Creek Clearcut Equivalent Acres Harvested | North Fork Elk River Clearcut Equivalent Acres Harvested | South Fork Elk River Clearcut Equivalent Acres Harvested |
|---|---|---|---|
| 1986 | 550 | 155 | 453 |
| 1987 | 255 | 129 | 175 |
| 1988 | 485 | 1,238 | 595 |
| 1989 | 224 | 488 | 99 |
| 1990 | 486 | 757 | 152 |
| 1991 | 439 | 309 | 200 |
| 1992 | 327 | 421 | 1 |
| 1993 | 318 | 304 | 313 |
| 1994 | 492 | 636 | 93 |
| 1995 | 75 | 676 | 0 |
| 1996 | 917 | 738 | 4 |
| 1997 | 1,117 | 683 | 483 |
| 1998 | 1,511 | 711 | 229 |
| 1999 | 409 | 82 | 0 |
| 2000 | 106 | 0 | 0 |
| 2001 | 596 | 7 | 71 |
| 2002 | 410 | 364 | 384 |
| 2003 | 450 | 639 | 2 |
| 2004 | 508 | 395 | 124 |

## Table 10. Survey data from Elk River Road.

| Station (Feet) | BS | FS | HI | Elevation | Left EOP | Centerline | Right EOP | Edge of Berm | Description | Elevation Left EOP | Elevation Centerline | Elevation Right EOP | Elevation Edge of Berm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BM1 | 5.15 | | 61.75 | **56.6** | | | | | Shiner on left edge of pavement adjacent to "Headwaters Forest Reserve" sign | | | | |
| BM2 | 0.97 | | 61.75 | **60.78** | | | | | Right (US, NE) corner bridge rail | | | | |
| BM3 | 1.2 | | 61.75 | **60.55** | | | | | NW corner bridge rail | | | | |
| Bm4 | 1.7 | | 61.75 | **60.05** | | | | | Top of 19.99' staff | | | | |
| BM5 | 5.06 | | 61.75 | **56.69** | | | | | Top of 16.66' staff | | | | |
| BM6 | 8.41 | | 61.75 | **53.34** | | | | | Top of 13.33' staff | | | | |
| 0 | | | 61.75 | | 5.81 | 6 | 6.6 | | Start at orange spray paint on left edge pavement south of concrete bridge on Elk River Rd | **55.94** | **55.75** | **55.15** | |
| 24 | | | 61.75 | | 5.52 | 5.85 | 6.58 | | | **56.23** | **55.9** | **55.17** | |
| 48 | | | 61.75 | | 6.74 | 5.94 | 6.32 | | 3' south bridge abuttment | **55.01** | **55.81** | **55.43** | |
| 72 | | | 61.75 | | 5.3 | 5.35 | 5.71 | | | **56.45** | **56.4** | **56.04** | |
| 96 | | | 61.75 | | 4.31 | 4.28 | 4.49 | | | **57.44** | **57.47** | **57.26** | |
| 120 | | | 61.75 | | 4.12 | 3.98 | 4.1 | | | **57.63** | **57.77** | **57.65** | |
| 144 | | | 61.75 | | 4.13 | 3.94 | 4.12 | | | **57.62** | **57.81** | **57.63** | |
| 168 | | | 61.75 | | 4.35 | 4.08 | 4.28 | | | **57.4** | **57.67** | **57.47** | |
| 192 | | | 61.75 | | 4.81 | 4.54 | 4.62 | | 2' north of abuttment | **56.94** | **57.21** | **57.13** | |
| 216 | | | 61.75 | | 5.3 | 4.95 | 4.81 | | 2' north of BM1 | **56.45** | **56.8** | **56.94** | |
| 240 | | | 61.75 | | 5.73 | 5.54 | 5.57 | | 5' south of large tree | **56.02** | **56.21** | **56.18** | |
| 264 | | | 61.75 | | 6.04 | 6 | 6.79 | | 1.5" south of "one lane bridge" sign, 5' north of large diam redwood | **55.71** | **55.75** | **54.96** | |
| 288 | | | 61.75 | | 6.6 | - | 6.82 | | | **55.15** | | **54.93** | |
| 312 | | | 61.75 | | 7.15 | 7.83 | 7.87 | | | **54.6** | **53.92** | **53.88** | |
| 336 | | | 61.75 | | 7.44 | 7.07 | 7.34 | | | **54.31** | **54.68** | **54.41** | |
| 360 | | | 61.75 | | 7.46 | 7.06 | 7.25 | | south end of ellow stripeadjacent to "35MPH" sign | **54.29** | **54.69** | **54.5** | |
| 384 | | | 61.75 | | 7.32 | 7.08 | 7.16 | | | **54.43** | **54.67** | **54.59** | |
| 408 | | | 61.75 | | 7.44 | 7.03 | 7.28 | | | **54.31** | **54.72** | **54.47** | |
| 432 | | | 61.75 | | 7.6 | 7.08 | 7.27 | | | **54.15** | **54.67** | **54.48** | |
| BM7 | | 5.95 | 61.75 | **55.8** | | | | | Nail in pole by bigfruit tree, town side of Kallo Yard | | | | |
| BM7 | 5.2 | | 61 | | | | | | | | | | |
| 456 | | | 61 | | 6.58 | 6.36 | 6.82 | | | **54.42** | **54.64** | **54.18** | |
| 480 | | | 61 | | 6.53 | 6.41 | 6.87 | | North side of yellow stripe @ pole with BM7 | **54.47** | **54.59** | **54.13** | |
| 504 | | | 61 | | 6.22 | 6.66 | 7.41 | | | **54.78** | **54.34** | **53.59** | |
| 528 | | | 61 | | 6.58 | 6.36 | 6.82 | | Middle yellow stripe south of culvert @ REOP | **54.42** | **54.64** | **54.18** | |
| 541.2 | | | 61 | | | 6.9 | 7.69 | 8.41 | Culvert | | **54.1** | **53.31** | **52.59** |
| | | | 61 | | 6.2 | 6.99 | 8 | | Just above LEOP is break in slope at 7.68 | **54.8** | **54.01** | **53** | |
| 552 | | | 61 | | 6.32 | 6.92 | 8.01 | | Section of road with broken pavement | **54.68** | **54.08** | **52.99** | |
| 576 | | | 61 | | 5.99 | 6.79 | 7.64 | | | **55.01** | **54.21** | **53.36** | |
| 576.2 | 33.5 | | 61 | | | 6.94 | 7.87 | 8.17 | Break in Berm | | **54.06** | **53.13** | **52.83** |
| 600 | | | 61 | | 5.78 | 6.47 | 7.55 | | | **55.22** | **54.53** | **53.45** | |
| 624 | | | 61 | | 5.65 | 6.36 | 7.46 | | | **55.35** | **54.64** | **53.54** | |
| 648 | | | 61 | | 5.15 | 5.97 | 7.14 | | Base of big stump | **55.85** | **55.03** | **53.86** | |
| 672 | | | 61 | | 4.66 | 5.6 | 6.44 | | Paved | **56.34** | **55.4** | **54.56** | |
| 696 | | | 61 | | 4.2 | 5.3 | 6.44 | | | **56.8** | **55.7** | **54.56** | |
| 720 | | | 61 | | 3.8 | 4.59 | 6 | | ~Crit dip of watercourse | **57.2** | **56.41** | **55** | |
| 744 | | | 61 | | 2.72 | 3.44 | 4.97 | | ~3' South of Pole | **58.28** | **57.56** | **56.03** | |
| 768 | | | 61 | | 1.79 | 2.26 | 2.28 | | North End of Survey | **59.21** | **58.74** | **58.72** | |